SERPENTINES OF THE CENTRAL COAST RANGES OF CALIFORNIA.[1a]

(Plates XXXIV and XXXV.)

By H. E. KRAMM.

Communicated by Prof. J. C. Branner.

(*Received June 6, 1910.*)

Contents.

Introduction.

It is the object of this paper to present a petrographical description of serpentines in the central coast ranges of California.

The areas under discussion are found in the region south from Clear Lake in Lake County to the New Almaden Mine in Santa Clara County, a distance of about 140 miles, and aggregates perhaps 300 square miles.

[1a] A thesis for the degree of A.M. presented to the Department of Geology of Stanford University, May, 1910.

These serpentines were designated by G. F. Becker as being derived from sedimentary rocks, which he believed had obtained the magnesia necessary for their transformation into serpentine by a process of substitution.[1] Previous to his report which appeared in 1888 some Colusa County serpentines had been described by M. E. Wadsworth as lherzolite serpentines.[2] Others, the Mount Diablo,[3] Potrero,[4] Angel Island,[5] San Francisco Peninsula[6] and the Oak Hill[7] serpentines have since been shown to be derivatives of eruptives.

These latter areas aggregate perhaps ten to fifteen square miles which is, according to Becker, about one per cent. of the total serpentines in the coast ranges. Their investigation, aside from having demonstrated that the rock is derived from eruptives, has also shown interesting variations in the serpentine itself.

Taking this into consideration, a study of the remaining areas seemed desirable, even though such might not produce new and startling facts.

The accompanying map shows the distribution of the rock in the central coast ranges. Existing maps proved of valuable assistance in the field as well as in the preparation of the map. While some of the data for it were thus obtained, other data were obtained by the writer, who is aware that there may be serpentines especially in Napa, Marin and Solano counties which may have escaped his attention.

[1] G. F. Becker, "Quicksilver Deposits of the Pacific Coast," Monograph XIII, U. S. G. S., 120–128, Washington, 1888.

[2] M. E. Wadsworth., "Lithological Studies," *Mem. Mus. Comp. Zool. Harvard College,* 1884, 129–132.

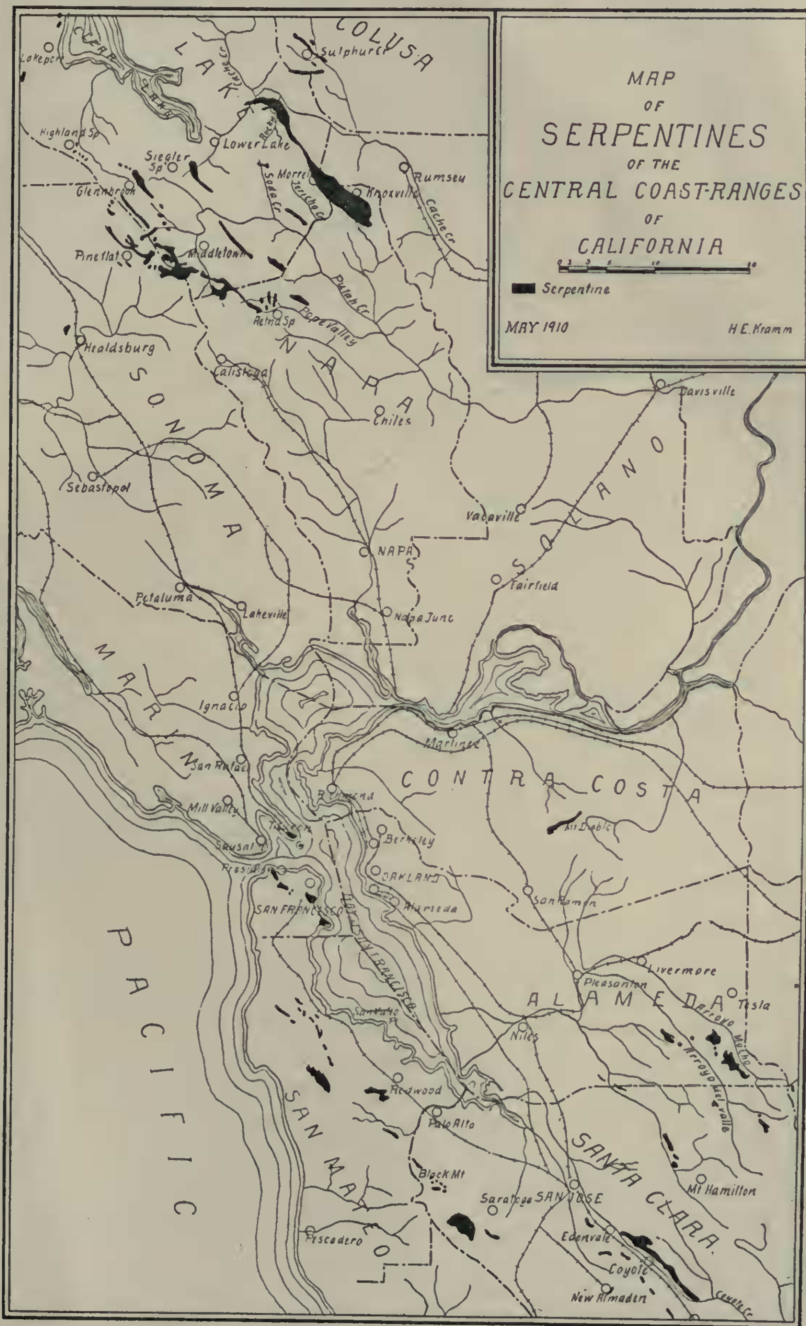
[3] H. W. Turner, "The Geology of Mount Diablo, California," *Bull. Geol Soc. Am.,* II., 388–391, 1891.

[4] C. Palache, "The Lherzolite Serpentines and Associated Rocks of the Potrero, San Francisco," *Bull. Geol. Dept., Univ. Cal.,* I., 164–169, 1894.

[5] F. L. Ransome, "The Geology of Angel Island," *Bull. Geol. Dept. Univ.* Cal., I., 219, 1894.

[6] A. C. Lawson, "Geology of the San Francisco Peninsula," 15th Annual Report U. S. G. S., 445, Washington, 1893–94.

[7] E. P. Carey and W. J. Miller, "The Crystalline Rocks of the Oak Hill Area near San José, Cal.," *Journal of Geol.,* XV., 160, 1907.


MAP
OF
SERPENTINES
OF THE
CENTRAL COAST-RANGES
OF
CALIFORNIA
Serpentine
MAY 1910
H.E. Kramm
COLUSA
LAKE
NAPA
SONOMA
SOLANO
MARIN
CONTRA COSTA
ALAMEDA
SANTA CLARA
SAN MATEO
PACIFIC
Sulphur Cr
Lower Lake
Rumsey
Knoxville
Middletown
Healdsburg
Calistoga
Chiles
Sebastopol
Vacaville
NAPA
Fairfield
Petaluma
Lakeville
Napa Junc
Davisville
Ignacio
San Rafael
Martinez
Mill Valley
Sausalito
Berkeley
OAKLAND
Alameda
San Ramon
SAN FRANCISCO
Livermore
Pleasanton
Tesla
Niles
Redwood
Palo Alto
Black Mt
Saratoga
SAN JOSE
Mt Hamilton
Pescadero
Edenvale
Coyote
New Almaden

General Location of the Serpentines.

For the sake of description and convenience the areas have been divided into districts. These are named and situated as follows:

I. The Sulphur Creek district is about twenty miles east of Clear Lake. It is situated about the headwaters of the Sulphur Creek, a tributary to Cache Creek, and embraces the Lake and Colusa County dividing line.

II. The Knoxville and Clear Lake district comprises all those serpentine areas which are found about the point at which Lake, Yolo and Napa counties meet. It is limited in the north by Cache Creek and in the south by Putah Creek. It also includes the areas found in the immediate neighborhood of Clear Lake.

III. The Mayacmas district is bounded in the north by Putah Creek. It embraces the serpentines found along the Mayacamas range, which from Mount St. Helena extends to the northwestwards.

IV. The San Francisco district takes in all areas of serpentine found on the San Francisco peninsula, and areas in the vicinity of San Francisco.

V. The Coyote Creek and Black Mountain district comprises all serpentines which are found in the country drained by the Coyote Creek, south of San Jose, besides these the serpentines found in the Black Mountain region.

VI. The Mount Diablo and Mount Hamilton district includes all serpentine areas which are found in the country between these mountains.

I. The Sulphur Creek Serpentines.

The serpentines of this district form two belts, each one several miles in length, and in width varying from 100 feet to one half mile. Besides these, there are two smaller areas.

The first and most important belt is encountered about 100 yards west of the Wilbur Springs Hotel. From here it extends five miles in a northwest direction, forming the backbone of a ridge which stands out prominently above the surrounding country. To the south it extends a distance of one mile, and closely approaches the second belt of serpentine.

The second belt has an east-and-west trend, and follows for about three miles the ridge that forms the Colusa and Lake County dividing line, then extends one mile to the west.

Of the two smaller areas one is found 100 yards northwest of the Wilbur Spring Hotel, the other is best located by the Wideawake quicksilver mine. Both aggregate only a small fraction of a square mile, but the former has attained a certain local fame, due to the abruptness with which it terminates, exposing an almost perpendicular height of about 100 feet, which is known as the lovers' leap.

With the exception of the last the serpentine outcrops are very low. They seldom protrude more than a few feet above the surrounding soil, the removal of which keeps pace with the erosion of the rock. All stages of decomposition can be observed. Very fresh rock is found where Sulphur Creek cuts the first named belt of serpentine. It is exceedingly brittle, of a dark green color, massive, and shiny individuals of pyroxene give it a mottled appearance. As it weathers it assumes a brownish color, and finally gives rise to a brown soil.

Thin sections from fresh serpentine show a colorless mass with a slight green tinge with now and then patches of a more intense green, the whole somewhat pleochroic. Crossed nicols reveal serpentine to be the predominating mineral, with enstatite, diallage and olivine less abundant. Minor quantities of picotite, chromite and magnetite are present.

The microscopical investigation was supplemented by a chemical analysis made by the writer in the mineralogical laboratory of Stanford University, of fresh serpentine from the bed of Sulphur Creek, with the following results:

The analysis shows a very basic rock, and points towards a peridotite. It corroborates the microscopical investigation. Using the theoretical formula for serpentine the approximate ratio of serpentine to other minerals present can be calculated by assuming that all the water goes with the serpentine. The ratio thus obtained is four to one.

The above presented evidence shows that the parent rock was an eruptive, very basic, and contained the minerals which define a lherzolite. The serpentine is therefore a lherzolite serpentine.

Analysis of Serpentine, Sulphur Creek, Colusa Co.
H. E. Kramm, analyst.

	Per Cent.
SiO_2	37.62
Al_2O_3	1.20
Fe_2O_3	8.60
FeO	2.15
MgO	37.59
CaO	2.49
Na_2O	.27
K_2O	trace
H_2O	10.46
Cr_2O_3	.36
TiO_2	trace
	100.74

While the foregoing only treats the massive facies of the serpentine it is of interest to study the other facies present. The rock as a whole shows an advanced state of decomposition. It is much shattered and slickensided, due no doubt to the increase of volume of the parent rock in the course of hydration into serpentine, and the resulting pressure. Angular fragments, bluish-green to brown in color, crumbling away under slight pressure often enclose rounded boulders of an apple green tough serpentine. These are traversed in all directions by numerous veins of chrysotile, reaching sometimes a thickness of two centimeters. The chrysotile being more resistant towards weathering stands out from the main bulk. This facies is especially prominent where the creek cuts the first belt of serpentine. A similar rock is found at the Potrero in San Francisco and has been described by C. Palache.[8]

The decomposition of the serpentine changes its structural features. The usually massive fresh rock often becomes granular. Numerous veinlets of black magnetite give it a banded appearance and a high specific gravity. Cavities form, which are colored white by magnesite or hydromagnesite. (See Plate XXXIV, Fig. 1.) At this stage the serpentine has more or less transformed into a silicious mass, which is tough, and not breaking exhibits the characteristic greasy luster of opal, while remnants of the serpentine are

[8] C. Palache, "The Lherzolite Serpentines and Associated Rocks of the Potrero, San Francisco," *Bull. Geol. Dept. Cal.*, I., 166, 1894.

still recognizable, bastite being the most resistant. The silicious substance assumes a red or yellow color upon weathering, due to the oxidation of iron compounds, and finally crumbles away. This feature of the rock is fully described by A. Knopf.[9]

The serpentine is associated with a coarse-grained somewhat metamorphosed sandstone, in which biotite is prominent and which in places assumes the character of a fine-grained conglomerate. To the south of the first belt where the Manzanita Mine is located shales are found. The sandstone, according to G. F. Becker, is of Knoxville age.[10] This he substantiates by the finding of impressions of *Aucella Piochii* in the metamorphosed rock close to the Manzanita Mine on Sulphur Creek. Although no direct contact was observed by the author, it being covered by soil and brush, the approximate contact is marked by a more intense degree of metamorphism of the sandstone. It is here exceedingly hard and responds to the blow of the hammer with a metallic ring. In the bed of Sulphur Creek was also seen serpentine which carried angular fragments of the sandstone.

The contact metamorphism is not accompanied by crystalline schists, but is such as would be caused by a strong thermal action.

II. The Knoxville and Clear Lake District Serpentines.

The Knoxville Serpentine.

The district as has been defined is the strip of country bounded in the north by Cache Creek and in the south by Putah Creek. Its principal body of serpentine which covers an area of approximately forty square miles is perhaps the largest found in the cntral coast ranges. A narrow strip a few hundred feet wide runs parallel to Perkins Creek, two miles south of it. Crossing Cache Creek it broadens out, capping the ridge that has its highest point a mile southwest of the Shamrock Mine. At this point the serpentine has a width of about one mile. Maintaining this width, it follows

[9] A. Knopf, "An Alteration of Coast Range Serpentine," *Bull. Dept. Geol. Univ. Cal.*, IV., 425, 1906.

[10] G. F. Becker, "Quicksilver Deposits of the Pacific Coast," Monograph XIII., U. S. G. S., 183, Washington, 1888.

Rocky Creek south to its headwaters, forming a series of low peaks to the east of the creek. Occasional outcrops from here have a northwest-southeast trend, establishing a connecting link with the main body of serpentine, which following the same general direction gradually expands to a width of four miles, passes to the south of Knoxville, and finally terminates about three miles southeast of Knoxville in a series of rugged outcrops.

The area as a whole presents a monotonous aspect. One sees a series of rocky ridges densely covered with brush and here and there a tree.

In the northwest, Rocky Creek cuts its way through the area and at places exposes steep walls of serpentine a hundred and more feet high, rising almost perpendicularly. The bed of the creek is strewn with big boulders which sometimes reach a diameter of ten feet. This is especially noticeable near the Shamrock Mine.

In the southwest Hunting Creek has cut a deep narrow canyon which gradually widens out towards the south, and into which enter a number of smaller canyons formed by tributaries. As at Rocky Creek the serpentine here is exposed presenting steep walls, and its débris covers the creek bed.

The headwaters of Davis Creek which drains to the north, and is a tributary to Cache Creek, have left their imprints upon the topography. Excellent opportunities for collecting fresh specimens are afforded by these drainage channels.

In many respects the serpentine resembles the one found at Sulphur Creek. It however presents a greater variety of colors. They vary with the degree of weathering the rock has undergone and the amount of iron it possesses. Upon fresh surfaces it is usually a dark green or almost black. The first indication of weathering is a yellow or a red color. Exposure to the atmosphere and the sun bleaches the serpentine and causes a decrease in hardness. A greenish-white slippery mass which resembles talc is the end product.

While here, as in the Sulphur Creek region, the shearing action is intense, and manifests itself in many slickensided fragments, the nodular variety of serpentine is not represented to any extent. This indicates a more homogeneous original mass.

Of the many hand specimens collected from this region one is of especial interest (Plate XXXIV, Fig. 2). It was taken from an outcrop on the western bank of Rocky Creek, and about one half mile south of the Shamrock Mine. It is a bastite pseudomorph after a pyroxenite and has beautifully retained its characteristic structure. The individual crystals are of a lighter green tint. The whole mass appears somewhat dull with now and then a glittering surface. The rock is massive, tough, due to the interlocking crystals and is easily scratched by a knife.

The microscope reveals that alteration has not been complete. Prismatic crystals of enstatite with prominent cleavage at right angles to the elongation of the fibers are still present. The slide shows bastite, some antigorite and a few minute veins of chrysotile.

Of interest are numerous transparent grains irregularly distributed with a tendency to concentrate along the bastite bands. They present a medium high relief and are isotropic. Sometimes these grains approach octagonal outline, but mostly they are of oval shape. Optically they behave like spinel, the index of refraction of which, being lower than that of methylene iodide, differentiates it from garnet. Plate XXXV, Fig. 3 gives an idea of the spinel.

The same mineral was found in a pseudomorph after a websterite from Mount Diablo, where it is of a secondary nature, since it was not observed in fresh rock. This similarity of condition makes it safe to assume that it is a secondary mineral here also.

The total quantity of this variety of serpentine is a small one. The outcrop is surrounded by the kind of serpentine common in this area, which is altered to a considerable extent.

The nature of the primary rock is indicated by a thin section made of fresh serpentine in which remnants of olivine, enstatite and diallage are found. Other minerals present are picotite, chromite and magnetite.

The predominating rock with which the serpentine is associated is a medium-grained grayish-yellow sandstone interbedded with shales. As one follows the road from Lower Lake to Knoxville and approaches the serpentine, one sees enormous thicknesses of it exposed. The dip is high, usually near 90 degrees. The angles are not constant. They vary considerably, sometimes within a few hundred feet. It is possible to travel a short distance and measure any angle. The rock is compact, specked with grains of biotite and well consolidated.

Outcrops of what is evidently the same sandstone are found a few hundred yards northwest of Morrell within the serpentine mass. They resemble serpentine to such an extent that seen even from a short distance they are taken for it. They have the rugged appearance of serpentine outcrops and the same lighter tint green which it often assumes upon weathering. A close inspection reveals the grain of the sandstone, decided bedding planes, and a hardness which by far exceeds that of the serpentine. It also shows the intense degree of metamorphism. At places a slight schistosity has been developed. A thin section made of this rock contains the usual acid ground mass of a sandstone, a few flakes of biotite and considerable epidote.

Crystalline schists and boulders of metamorphic rock are found included in the serpentine on the crest of a ridge north of Knoxville. The serpentine is crushed to fine scaly masses resembling a shale.

About one half mile south of the Shamrock Mine a tributary to Rocky Creek cuts the sandstone which butts against the serpentine on the east of Rocky Creek. Narrow seams of interbedded shale which carry *Aucella Piochii* in abundance are exposed. Towards the serpentine the sandstone is strongly metamorphosed.

An actual contact of a shale with the serpentine is exposed by the Johnson shaft of the Knoxville Mine. The shale however does not seem to be much altered and it has not ben ascertained whether or not it contains fossils.

The mineralogical character of the serpentine combined with the above evidence demonstrates that it is derived from an eruptive rock which is intrusive into the Knoxville formation.

There are two smaller areas of serpentine in the vicinity of the Knoxville area. One is found about one mile south of Jericho Creek. It approaches Hunting Creek in the west. It extends in a northwestern direction approximately parallel to Putah Creek for four or five miles. Its width varies from a few hundred feet to one half mile. Bordering it in the north is found a dike of olivine basalt, in the south the metamorphosed sandstone.

The other area is exposed by the road from Lower Lake to Knoxville about six miles from the former. It is represented only by a few outcrops with an east-and-west trend.

Both areas have very low outcrops and mineralogically correspond with the principal body of serpentine described in the preceding pages.

The Clear Lake Serpentines.

A small area of serpentine is found on the ridge north of Borax Lake, west of Clear Lake and south of the Sulphur Bank Mine. No specimens were obtained from this area. Becker[11] describes the serpentine, which seems to resemble closely the one met with at Knoxville and Sulphur Creek. Analyses are given of two varieties of serpentine, the first is of a black impure looking mass with phenocrysts, which are probably bastite, the second is of a purer variety. For comparison they are here appended.

Analyses of Serpentine from Near Borax Lake, Lake County.
Analyst not stated.

	I. Per Cent.	II. Per Cent.
SiO_2	39.64	41.86
Al_2O_3	1.30	.69
FeO	7.76	4.15
MgO	37.13	38.63
Cr_2O_3	.29	.24
NiO	.33	trace
MnO	.12	.20
H_2O	13.81	14.16
	100.38	99.93

It is seen that in chemical character the serpentine closely approaches that of Sulphur Creek. The total iron although given here as ferrous probably includes also iron in a ferric state.

Another serpentine area is located by Siegler Springs and Howard Springs about seven miles southwest of Lower Lake. It has a northwest-southeast trend. At Siegler Springs its width is ap-

[11] Monograph XIII., U. S. G. S., p. 111, 1888.

proximately one half mile. It widens out towards Howard Springs, where it has a width of about one mile. From here a series of outcrops point to the southeast and can be followed for about three miles.

The serpentine, being more resistant towards erosion than the associated sandstone, occupies an elevated position in places rising several hundred feet. It is fairly well preserved, of a dark green color, with coarse phenocrysts of bastite, and is exceedingly brittle. Thin sections show that the rock is almost wholly made up of serpentine. Of original constituents enstatite and chromite only are found, while the mesh structure due to olivine is very prominent. Its similarity to the Knoxville serpentine leaves no doubt as to its origin from a lherzolite.

The road from Kelseyville to Cloverdale past Elliott Springs cuts several areas of serpentine. The first one to the east of the road is one and a half miles east of Highland Springs, and its extent is one quarter square mile. The second and most important one is met 200 yards south of Fowler. The road cuts it and exposes a vertical wall of 50 feet of serpentine of a bluish green color. Slickensided fragments and an advanced state of decomposition are pronounced features. Fresher specimens show the porphyritic appearance caused by protruding foliated crystals of bastite. The area covers one half square mile.

Single outcrops are found a mile north of Elliott Springs, near Elliott Springs, and also three quarters of a mile south of it on the slope of the mountain ridge which divides Sonoma from Lake County. All of the serpentines are intrusive in sandstones. A feature of the contact is the occurrence of glaucophane and muscovite schists thus pointing towards rocks of Franciscan age. Microscopically the serpentines resemble those of Howard Spring.

Serpentine is also found west of Clear Lake and in close proximity to it. There are three small areas. The most northern one borders Clear Lake and is best reached by following the road from Lakeport to Upper Lake. It is five miles from the first named place. Another area is a few hundred yards south of Lakeport to the west of the road leading to Kelseyville. The third area is found to the east of the road from Lakeport to Glenalpine about one mile from the latter place.

The serpentine of these areas occupies low dome-shaped hills, over which numerous boulders of the rock ranging in diameter from one to three feet are strewn. From dark green to greenish blue they show the typical lherzolite serpentine in all its stages of decomposition.

III. The Mayacmas District Serpentines.

A narrow strip of serpentine extends in a northwest direction for about twenty-four miles, following more or less closely the Mayacmas range. It is very irregular in shape.

Near Ætna Springs are found a number of small areas with low outcrops which seem to form a connecting link with the Pope Valley serpentine and the Mayacmas area. Beginning at the Ætna Mine a narrow belt can be traced to the northwest by a number of quicksilver mines, the Twin Peak, Corona, Mirabel and Great Western Mines which are situated on its contact. The outcrops are very low along this belt. The contact, which is with a sandstone in the north, is partly with a basalt, partly with a sandstone in the south. Brush and soil cover it and only occasional outcrops indicate the general direction of the serpentine. The width of the belt varies. At places it is a hundred feet wide, but never more than one half a mile. Several narrow bands branch off to the south approaching Mount St. Helena.

At the Great Western Mine the belt assumes greater dimensions. It becomes more than a mile wide and forms the crest of the Mayacmas range, which here has an altitude of 2,900 feet and gradually rises as Pine Mountain is approached to 3,500 feet. At Pine Mountain the Mayacmas range divides into three branches, all extending in a northwest direction. The most southern one consists of a series of ridges and peaks of which Geyser peak is best known. The Big Sulphur or Pluton Creek cuts a steep canyon on its northern flank, forming a dividing line with that range of which Mount Cobb is the highest point looming to a height of 4,500 feet into the skies. The range furthest north is not continuous with the Mayacmas range. Putah Creek cuts a deep canyon which isolates it. It reaches an altitude of about 3,000 feet and Mount Harbin and Mount Hanna are its prominent peaks.

Half of a mile west of Pine Mountain the serpentine ceases to be a continuous area. Isolated outcrops are found in three directions which have the general trend of the branches of the Mayacmas range. They are along the southern flank of the southern range and a number of quicksilver mines indicate the general direction. From the road connecting these mines they are seen as rugged barren masses, prominent on account of the bluish green color and the dimensions of the outcrop. Float of actinolite schist is quite abundant, and glaucophane schist is seen in place.

Another series of outcrops follows the range north of the Big Sulphur or Pluton Creek south of Mount Cobb. They are found as far west as the headwaters of Squaw Creek.

Occasional areas are also found north of Cobb Mountain, having a general trend towards Pine Mountain. The largest of these is a few hundred yards west of Glenbrook Springs and covers perhaps one half of a square mile.

The serpentine as a whole along this belt differs from the previously described ones in that it is in a more advanced state of decomposition. Specimens even of moderate freshness could not be obtained. The nodular variety is prominent in the neighborhood of Ætna Springs but the nodules also, are well on the way towards decomposition.

Where the serpentine is not slickensided, a feature which is predominant, the structure is granular. Serpentine with this structure seems to be more resistant. The outcrops are higher and are more bold. Often they are protected by a layer of moss. If such an outcrop then has jointing in approximately parallel lines it resembles sandstone to such an extent that to differentiate it, it is necessary to break the rock.

All slides made from specimens along this belt show similar features. Antigorite more or less stained with oxide of iron still shows the structure due to its origin from olivine in some slides, while in others decomposition has erased all genetic indications and nothing but a homogeneous greenish mass remains. Enstatite is still observed in fresher specimens and is besides chromite the only constituent of the original rock remaining behind. Diallage is not present, but since it gives rise to antigorite and seems to be more susceptible to decomposition than enstatite, it was probably also a constituent of the original rock. Traces of picotite with a broad surrounding mass of chromite are seen (Plate XXXV, Fig. 4), and veins of magnetite are in abundance. With an advance of decomposition the carbonates dolomite, calcite and magnesite appear. They have no crystalline form, but are either granules enclosed in serpentine or vein filling.

The serpentine found near Glenbrook Springs differs somewhat from the above in structure and appearance. It is massive, well preserved and slickensided fragments are rare. It appears to be porphyritic, due to a yellowish brown ground mass which is very uniform and dotted by numerous green phenocrysts of bastite standing out prominently. Thin sections show that this coloration is caused by an abundance of oxide of iron.

ANALYSIS OF SERPENTINE FROM MAYACMAS RANGE.

H. E. Kramm, Analyst.

	Per Cent.
SiO_2	39.98
Al_2O_3	1.12
Fe_2O_3	13.19
FeO	1.05
MgO	30.49
CaO	.46
Na_2O	.28
K_2O	.25
H_2O	13.26
Cr_2O_3	trace
TiO_2	trace
	100.08

Serpentine is also found on the road from Middletown to Lower Lake, about two miles south of Guenoc. The area has a northwest-southeast trend, an average width of a quarter mile and a length of about five miles, forming a low ridge which rises not more than a few hundred feet above the surrounding country. The serpentine is well preserved, and its similarity to the Knoxville serpentine makes further comment unnecessary. Herewith is given an analysis of a Mayacmas range serpentine made by the writer. It was taken near the Missouri Mine about six miles northwest of Pine Mountain and is fairly well preserved.

Serpentine is also found bordering Pope Valley. The extent of these areas however has not been determined. Specimens from these areas show a typical lherzolite serpentine.

IV. The San Francisco District Serpentines.

The San Francisco Peninsula Serpentines.

Serpentine is found in the vicinity of San Francisco and at San Francisco proper. According to Lawson[12] they are grouped into three linear tracts which traverse the peninsula of San Francisco in a northwest-southeast direction. The most northern one extends from Fort Point on the Golden Gate to Hunters Point on the Bay of San Francisco, a length of ten miles and with a maximum width of 1½ miles. It is probably a continuous belt although sand and alluvium cover portions of it and make it appear as four distinct areas. These areas have the character of laccolites or dikes which are intrusive into the Franciscan series of rocks.

The character of the serpentine has been in detail investigated by Palache.[13] It is represented in two facies which are named the slickensided and the massive facies. The slickensided is similar to the one at Sulphur Creek described by the writer. The massive facies is dark green in color, translucent on thin edges and has a splintery fracture. The parent rock is a lherzolite.

Analysis of Serpentine from Presidio, San Francisco.

J. D. Easter, Analyst.

	Per Cent.
SiO_2	39.60
Al_2O_3	1.94
FeO / MnO	8.45
MgO	36.90
Cr_2O_3	.20
H_2O	12.91
	100.00

FeO in this case probably also includes Fe_2O_3.

[12] A. C. Lawson, "Geology of the San Francisco Penninsula," 15th Annual Report U. S. G. S., 445, Washington, 1893.

[13] C. Palache, "The Lherzolite Serpentines and Associated Rocks of the Potrero, San Francisco," *Bull. Geol. Dept. Univ. Cal.*, I., 164–169, 1894.

An analysis of a Presidio serpentine made by Easter is given on account of the similarity with the one made by the writer on Sulphur Creek serpentine.

The second belt of serpentine occupies the southeastern portion of Buri-Buri ridge from San Andreas Lake to San Mateo Creek, and nearly the whole of Las Pulgas ridge, with a total length of 11½ miles and a maximum width of over one mile.

The third belt consists of a linear group of dike-like masses distributed along San Mateo Canyon between Sayer and Cahill ridges, on the pass between Cahill and Fifield ridges, and thence obliquely along Fifield ridge and across San Pedro Valley nearly to the ocean. The linear extent is six miles. There are also some few minor outcrops not referable to these belts.

All these serpentines exhibit similar features to those which Palache designated as lherzolite serpentine.

The Angel Island Serpentine.

Angel Island is situated in the bay of San Francisco 3½ miles north of the city of San Francisco. The geology of the island has been described by Ransome. Serpentine is found along the western portion of the island as a large dike having a maximum width of 500 feet. Intrusive into the San Francisco sandstone, it has metamorphosed it to some extent. The two facies, the slickensided and the massive are present. The slickensided differs from the one found at the Potrero in that the nodules are not as large and the matrix is less broken.

Analysis of Serpentine from Angel Island.

F. L. Ransome, Analyst.

	Per Cent.
SiO_2	42.06
Al_2O_3, Fe_2O_3	2.72
FeO	2.88
MgO	39.53
H_2O	12.04
	99.23

The massive facies is of unusual interest. It is made up of interlocking crystals of diallage with small amounts of magnetite and possibly some chromite. It would therefore correspond to a diallagite.

An analysis made by Ransome upon serpentine taken from a nodule of the slickensided facies is given above:

The Tiburon Peninsula Serpentine.

Although a narrow channel of the San Francisco Bay separates it the Angel Island serpentine is probably continuous with the one which is found north of it at the extreme tip of the Tiburon peninsula. It covers an area of perhaps one square mile. The road following the western shore line exposes the slickensided facies about 100 yards east of the ferry station.

The serpentine is much decomposed but the nodules, which often are several feet in diameter show fairly fresh serpentine which is very brittle. Vein serpentine is common.

The outcrops of this part of the area are small. The soil is of a reddish color and vegetation is scant. The crest of the ridge presents different features.

Outcrops reach a height of about 15 feet and consist of the siliceous mass, to which serpentine gives rise, and which is known in the coast ranges as the quicksilver rock. From a distance they resemble a conglomerate, close inspection however reveals the honeycombed tough silicious mass with magnesite stains here and there. Remnants of the serpentine can still be observed. The whole presents a rugged appearance. Magnesite float is abundant.

Slides of the fresh serpentine show the following minerals bronzite, diallage chromite and magnetite. The mesh structure due to olivine is prominent.

V. The Coyote Creek and Black Mountain Serpentine.

Serpentine is also found on what is known as the Los Lagrinas ridge a part of the Mount Hamilton range south of San Jose east of the Coyote Creek in Santa Clara County. The ridge consists of a series of kidney-shaped hills bordering the valley in the east, and reaching a maximum elevation of 300–400 feet above the valley level. About four miles south of Coyote station is the extreme southern end of the serpentine area, which covering the western slope of the ridge extends north to within one half mile of Edenvale.

What is probably an extension of this area, separated by alluvium is found on the opposite side of Santa Clara Valley. It follows a group of well-rounded crests which in a wide circular sweep reach to within four miles of San Jose. This area is known as the "Oakhill," and its crystalline rocks are described by Carey and Miller.[14]

The serpentine here is of a dike-like nature intrusive into radiolarian charts and sandstones of Franciscan age. It is variable in character. A massive phase shows glistening phenocrysts of diallage in a dark-green ground mass of serpentine which grades into a diallagite. The structural and mineralogical composition of the serpentine indicates that it is derived from a peridotite containing olivine, diallage and magnetite, with enstatite but sparingly present.

Associated with the massive green serpentine, which is predominant, is found the slickensided facies and the "mottled" serpentine. The latter consists of the green serpentine to which white colored spots varying in size to a diameter of two inches give a mottled appearance. The white substance may possibly be magnesium silicate. A partial analysis of massive conchoidal serpentine is here appended. Plate XXXV, Fig. 5 represents a phase of the mottled serpentine.

Of much interest is the associated olivine-gabbro which on one hand passes into peridotite and pyroxenite, and on the other into hypersthene gabbro and norite. An analysis of what may be considered a pyroxenite-peridotite consisting principally of diallage with small quantities of olivine partly transformed into serpentine, and some magnetite was made by the writer and is given below.

The serpentine of the main area which follows the Los Lagranas ridge does not differ from the one above described. It is intrusive into Franciscan cherts and sandstone. The area is almost destitute of soil and the barren slopes are strewn with boulders of the dark green rock. The outcrops are low and seldom protrude more than three feet above the surrounding soil. The massive facies is predominant. A feature is the abundance of magnesite which is found as float, and also in veins of considerable size.

Mineralogically the serpentine is a lherzolite serpentine. The mass as a whole appears to be uniform, but variations occur. A

[14] E. P. Carey and W. J. Miller, "The Crystalline Rocks of the Oak-Hill Area near San José, Cal.," *Jour. of Geol.*, XV., 160, 1907.

small lenticular body of pyroxenite is found about one quarter mile southeast of Coyote station. It is made up entirely of enstatite which is unaltered, and an analysis of which by the author is here given.

ANALYSES.

	Serpentine. I. Per Cent.	*Pyroxenite-peridotite.* II. Per Cent.	*Enstatite-pyroxenite.* III. Per Cent.
SiO_2	37.71	42.76	56.98
Al_2O_3	1.81	5.71	1.73
Fe_2O_3	10.47 (with FeO)	3.16	4.04
FeO		3.30	4.18
MgO	35.60	27.11	27.40
CaO	——	10.03	3.26
Na_2O	——	2.24	.59
K_2O	——	.49	.35
H_2O	——	4.85	2.04
Cr_2O_3	——	.22	.09
TiO_2	.09	.17	none
	85.68	100.04	100.66

I. Serpentine of the Oakhill area by U. S. G. S. Analyst not stated.
II. Pyroxenite-peridotite of Oakhill area. H. E. Kramm, analyst.
III. Enstatite-pyroxenite from near Coyote. H. E. Kramm, analyst.

South of the Oak-Hill area on the west side of Santa Clara valley, opposite the Coyote area, and having an approximately parallel trend with it, are several isolated areas of serpentine. The most northern one terminates on the road leading from San Jose to the New Almaden Quicksilver Mine. The most southern one is found about two miles northwest of Morganhill. A small area is also found near New Almaden.

The serpentine in general resembles that of the Coyote area, but shows a somewhat greater degree of decomposition.

About three miles southwest of Redwood in San Mateo County is a considerable area of serpentine. Its maximum width is somewhat over a mile, its linear extent four miles with a trend northwest-southeast.

Smaller areas are also found at the following places: one east of Searsville Lake about six miles west of Palo Alto, several south of

Black Mountain and one about four miles south of Saratoga. All of these are mapped in the Santa Cruz folio of the U. S. G. S.

Small pyroxenite bodies which consist of diallage are frequent in the Black Mountain areas. A feature of the Redwood area is tremolite secondary after serpentine, and talc after tremolite.

The similarity of the serpentine itself to that of the Coyote area makes further comment unnecessary.

VI. The Mount Diablo and Mount Hamilton Serpentines.

A lherzolite serpentine and a websterite are found at Mount Diablo in Contra Costa County. According to H. W. Turner[15] the area as a whole is dike-like, its length about five miles and its average width less than one half mile. The peridotite has largely been converted into serpentine, but specimens are still found which contain olivine, enstatite and diallage.

The pyroxenite is made up of bronzite and diallage, and is most prominent on the southwestern part of the area, occupying approximately one quarter of a square mile, but is also found at various other parts of the area.

The dike nature of the serpentine is best shown where the Arroyo del Cerro and its branches cut across the area east of the western fork of Pine Creek. The serpentine here varies in width from a few feet to 150 feet, and is enclosed in dark calcareous shales containing at several points near the serpentine "*Aucella Piochi*," with a strike and a dip about that of the shales which enclose it.

North of the serpentine area is found a diabase and the Knoxville sandstone, to the south it is bordered by metamorphosed sandstones.

A gabbro crops out north of the point where the serpentine dike crosses Bagley Creek. Between this gabbro and the serpentine lies like a body of *Aucella*-bearing shale, and up to present time no genetic connection between the two has been demonstrated.

The following analyses are given:

[15] H. W. Turner, "The Geology of Mount Diablo," *Bull. Geol. Soc. Am.*, II., 383, 1891.

ANALYSES OF SERPENTINES, MOUNT DIABLO.

	I.	II.	III.	IV.
SiO_2	53.25	36.57	40.50	41.52
P_2O_5	——	——	trace	——
Cr_2O_3	.54	.33	.41	——
Al_2O_3	2.80	.95	.78	1.57
Fe_2O_3	.69	7.29	4.01	3.50
FeO	5.93	.37	2.04	1.07
NiO	.07	.31	.11	——
MnO	.09	.10	.13	.29
CaO	16.22	.14	.39	.44
MgO	19.91	40.27	37.43	36.84
Na_2O	.19	.31	.28	——
K_2O	trace	trace	.16	——
H_2O at 105° C.	.05	.94	2.81	3.32
H_2O above 105° C.	.24	12.43	10.94	12.51
	99.98	100.01	99.99	101.06

I. Fresh pyroxenite with some olivine. W. H. Melville, analyst.
II. Bastite with fine seams of chrysotile. W. H. Melville, analyst.
III. Serpentine. W. H. Melville, analyst.
IV. Serpentine weathered interwoven with quartz and calcite. W. H. Melville, analyst.

Areas of considerable extent are found about fifteen miles southeast of Livermore to the west of the Arroyo Mocho in Contra Costa County, a few miles north of the Santa Clara and Contra Costa dividing line.

Other areas are to the west of the Arroyo del Valle to the south of Livermore in Contra Costa County, and in Santa Clara County. Still others are about six miles to the northwest of Mount Hamilton in Santa Clara County.

The location of these areas is best shown by the accompanying map.

These areas were not visited by the writer, but specimens of the serpentine are in the Stanford University collection.

Some of these are altered to the greenish-yellow slippery mass in which all genetic indications are obliterated; others exhibit the characteristics of a lherzolite serpentine. The presence of lenticular bodies of pyroxenites is indicated by specimens of diallagite and enstatite-pyroxenite which come from the serpentine areas northwest of Mount Hamilton.

Age of the Serpentines.

The similarity mineralogically and chemically of the serpentines makes it reasonable to suppose that the intrusion of its parent rock took place simultaneously throughout the coast ranges of California.

In the preceding pages, under areal description, it has been shown that in the Sulphur Creek and Knoxville districts, beds carrying *Aucella Piochii* are strongly metamorphosed by serpentine intrusion. The evidence points to a time of intrusion following the deposition of the Knoxville beds. This agrees with evidence obtained by H. W. Turner at Mount Diablo and with that of Fairbanks.[16]

Fairbanks reports Knoxville beds in which he found *Aucella Piochii* to be upturned and broken by serpentine masses. He puts on record other instances showing a shattering and metamorphosing of the Knoxville sandstone by the serpentine, and speaks of the finding of fragments of Knoxville shale in the serpentine and of serpentine in the Knoxville shale and sandstone. It is his opinion that the intrusion of the peridotite masses was at least partly responsible for the unconformity between the Chico and Knoxville beds.

The serpentines of the southern areas under discussion are usually associated with the Franciscan series of rocks, cherts and sandstones. Evidence which points to the time of intrusion of these dikes has to the writer's knowledge not been found up to the present time. This is to some extent caused by the lack of the Knoxville formation where the serpentine occurs.

Quicksilver in Connection with the Serpentine.

It is hardly possible to discuss the serpentines of the Coast Ranges without also bringing in quicksilver, and the relation which exists between its deposits and the serpentine.

The well known name "quicksilver rock" implies that decomposition product of the serpentine, which is a mixture of carbonates, compounds of iron and the three forms of silica quartz, chalcedony and opal. This rock occurs as dike-like masses in the body of the

[16] *American Geologist,* IX., 161–166, 1892.

serpentine itself, but is most common on contacts with the surrounding country rock, shale or sandstone.

The quicksilver is found filling existing pores, cracks and fissures of this rock. A few cases are known in which the ore is found in sandstone, which however is always in close proximity of serpentine bodies.

The principal ore is cinnabar. Mercury in a free state, metacinnabarite, and calomel are of less importance. The most common associates are marcasite, pyrite and chalcopyrite.

Under high temperature and pressure, in the presence of sulphohydrates and carbonates of the alkalies, mercury is in solution as the soluble salt $HgS + 4Na_2S$. Release of pressure, cooling especially in the presence of ammonia, dilution of the mineral-bearing solution, excess of hydrogen sulphide and the presence of bituminous substances are all factors which enter into the precipitation of the ore, bituminous matter leading towards a total reduction.

The intrusion of the peridotite masses in shattering the country rock provided channels through which the mineral-bearing waters circulated. These waters not only deposited the ore, but it is reasonable to suppose, that they were also to some extent instrumental in the decomposition of the serpentine. That conditions in this cherty decomposition product were exceptionally favorable for the deposition of the ore is substantiated by the fact that to the writer's knowledge cinnabar has never been found in the serpentine itself, nor is it found to any extent in the country rock. The few cases known in which the ore is found in sandstone show the sandstone to be of porous nature and as has been said located in the neighborhood of serpentine dikes.

As to the source of the quicksilver, Dr. Becker[17] suggests the base granite which underlies all sedimentary rocks in the Coast ranges.

Mineralogy of the Serpentines.

Primary Minerals.

The primary rock, as has been shown, with the exception of lenticular bodies of pyroxenites, is badly altered. Primary minerals

[17] G. F. Becker, "Quicksilver Deposits of the Pacific Coast," Monograph XIII., U. S. G. S., 449, Washington, 1888.

named in the foregoing are olivine, enstatite, bronzite, diallage, picotite and chromite.

Olivine is present only in the freshest variety of the rock and is even there not discernible in the hand specimen. Under the microscope it shows high relief, and is colorless. Cleavage cracks traverse it, which are often at rectangular position to each other and are usually filled with black opaque masses of magnetite. Crossed nicols show that in these cleavage cracks serpentinization has taken place and given rise to the mesh structure with small rounded fragments of the olivine occupying the central part of a mesh. A number of these rounded fragments usually extinguish together and thus indicate the size of the original crystal. Its lack of cleavage, its high relief and its bright interference colors distinguish it from the pyroxenes.

Enstatite is seen in the hand specimen as coarse prismatic crystals of a dark green color and with shiny cleavage surfaces which are parallel to the longer axis. Bastite is a pseudomorph after it, but can be recognized from it in that the crystals are easily scratched by a knife and are of a lighter green color. Under the microscope enstatite is seen in coarse platy crystals with a medium relief and a slight pleochroism from colorless to a light green. The cleavage is prominent. When basal sections are present, they sometimes present a dim prismatic cleavage.

Interference colors are of the first order, usually a bright yellow, the extinction is parallel and the slower ray is parallel to the elongation of the crystal. Plates parallel to the principal cleavage do not give an interference figure, which distinguishes it from bastite. Intergrowths with diallage are frequently observed.

Diallage is not quite as abundantly represented as enstatite. Under the microscope crystals of irregular outline are seen which resemble enstatite in cleavage lines and pleochroism. Crossed nicols however reveal bright interference colors, red and blue of the second order, and an oblique extinction. The maximum angle made with the principal cleavage was found to be 42 degrees. The slow ray is parallel to the elongation of the crystals. Besides the perfect (100) pinacoidal cleavage a well developed prismatic cleavage is seen in basal sections. Of enstatite and diallage the former appears to be more resistant towards serpentinization. Partially altered fragments of it were even found in nearly decomposed serpentine.

Bronzite does not differ much from enstatite. Due to its higher iron content it has higher interference colors, red of the first order to blue of the second order, and is as a rule pleochroic from colorless to a bright yellowish-green.

Of the minor constituents *picotite* is probably the most interesting. Its grains are of considerable size and irregular in outline. They were always found to be surrounded by black opaque masses resembling either chromite or magnetite which also fill numerous cracks traversing the crystal in all directions. (See Plate XXXV, Fig. 4.) It is of a coffee-brown color, has a high relief and is isotropic.

It was possible to isolate some of these crystals by digesting with hydrochloric acid and passing the residue through Thoulet solution, then separating the picotite by hand. The crystals were .5 mm. in diameter, glassy and hard enough to scratch quartz.

The black coating was stripped off and subjected to the action of a magnet. It was not magnetic and gave chromium reactions before the blowpipe. It is therefore chromite.

A series of slides made of specimens of serpentine varying in degree of decomposition revealed interesting facts. As the decomposition advances the outer opaque covering increases in size while the picotite decreases. In a fairly decomposed serpentine the picotite was still visible as a dot. In a much decomposed specimen, picotite disappears and only the irregular masses of chromite remain. It seems therefore that chromite is secondary after picotite.

Chromite itself was found as a primary constituent. It differs from that considered as secondary in that the masses assume a more geometrical outline. They are usually opaque, sometimes slightly translucent with a reddish brown tint.

Considerable quantities of chromite are known to occur in connection with the serpentine, but are not utilized commercially at the present time. Dr. Becker mentions chromic iron as occurring not far from the Royal claim near Knoxville. It is of nodular form in a seam which has been exposed by the weathering of the serpentine. The writer has not been able to locate this.

Another noteworthy place where chromite is found in quantities is at Cedar Mountain in Alameda County. An analysis of chromite from this locality corresponds closely with that of a mineral intermediate between picotite and chromite from a dunite from Dun Mountains in New Zealand, which for comparison is appended.

	I.	II.
SiO_2	none	——
Al_2O_3	18.79	12.13
FeO	16.99	18.01
CaO	trace	——
MgO	8.41	14.08
Cr_2O_3	55.74	56.54
NiO } CaO	trace	trace
MnO	trace	0.46
H_2O	.09	——
	99.82	101.22

I. Chromite from Cedar Mountain. H. E. Kramm, analyst.

The mineral was purified by powdering it and passing through Thoulet solution. All iron was determined in the ferric state and calculated to ferrous iron. There was no doubt ferric iron present, but the amount could not be determined on account of the difficulty of getting chromite into solution.

II. Chromite-Picotite from New Zealand. Mineralogy, 6th ed. Dana, p. 228. Analyst T. Petersen.

Secondary Minerals.

The course of hydration and subsequent decomposition of the serpentine necessitates a change of molecular arrangement, and gives rise to a number of secondary minerals. According to Tschermak the conversion of olivine gives rise to serpentine, magnesite, limonite and silica. It seems very probable that the excess of magnesia will combine with free silica to form secondary serpentine. This is substantiated by the fact that fissures in the rock are invariaby filled with chrysotile.

Decomposition and the action of ground waters assist in the development of another series of minerals which are probably oxide of iron, magnetite, hydromagnesite and vein serpentine. It is reasonable that this vein serpentine is not necessarily confined to the serpentine body itself, but may find its way into the surrounding country rock, where under favorable conditions it is deposited.

This would explain the occurrence of serpentine veins in sandstones, a feature observed in the Coast Ranges and construed by Dr. Becker[18] as showing the conversion of the sandstone into serpentine.

While nearly all of the secondary minerals can be found in every serpentine locality in minor quantities, local conditions favor the accumulation of some few. Of minerals which are of a secondary nature serpentine itself is the most important. It is represented by its two varieties, antigorite and chrysotile.

The antigorite shows under crossed nicols as an aggregate of irregularly distributed minute bands and scales which have low interference colors, usually gray with a bluish tint. Due to the irregularity of distribution, extinction is compensatory.

Bastite is a variety of antigorite and is microscopically prominent in coarse prismatic phenocrysts, pseudomorphous after enstatite or bronzite. It has a prominent pinacoidal (100) cleavage and is distinguished from the pyroxenes in that it is soft and is readily scratched by a knife.

Under the microscope these pseudomorphs are irregular in outline, and consist of coarse bands of serpentine in parallel arrangement. A cross fracture is frequently observed, often at right angles to the fibers, but it may have any angle. The whole is somewhat pleochroic from colorless to light green. Extinction is parallel to the lines of prominent cleavage and the slow ray is parallel to the elongation. When alteration has been complete, the characteristic low bluish-tint interference colors of antigorite are exhibited. Using thin uniform sections these colors are raised as the degree of alteration becomes less and approach those of enstatite or bronzite. Thin cleavage plates give an interference figure.

The chrysotile consists of an aggregate of parallel fibers filling the numerous seams which traverse the rock in all directions. It has parallel extinction, the parallel position of the fibers and the bright interference colors, usually red or blue of the second order, make it easily distinguishable. Microscopically it is prominent as silky veins which often reach considerable thickness, and are the well-known serpentine asbestos.

[18] Ibid., p. 277.

Of the different types of structure, the mesh and the bastitic structure are invariably found. The former points towards an origin from olivine and fresh specimens often show remnants of this mineral in the center of the mesh. It consists of bands of serpentine which intersect irregularly, quite often in rectangular position to each other, surrounding aggregates of filled serpentine.

The bastitic structure is described under bastite, and needs no further comment.

No characteristic grate structure was observed. It is true, now and then a suggestion of it is seen.

Magnetite was never observed in fresh specimens of the rock but it is pronounced when the rock is altered. It then occupies cracks and seams in opaque irregular masses. Chemical and magnetic properties distinguish it from chromite. Large masses in connection with the serpentine are to the writer's knowledge not known in the Coast Ranges of California.

Magnesite is abundantly found as float and in veins of various sizes. It is usually massive, fine-grained, of a beautiful white color and with a conchoidal fracture. Besides being formed in the process of hydration of the primary minerals which give rise to serpentine, it is probably also produced when the serpentine breaks down.

The following analyses given by F. L. Hess[10] show the chemical character of the magnesite.

Analyses of Magnesite.

	I.	II	III.
SiO_2	2.15	.30	49.85
Al_2O_3	1.22	.16	3.45
Fe_2O_3	1.16	.38	.18
CaO	5.28	1.34	.48
MgO	41.01	45.86	21.53
CO_2	48.72	51.80	23.96
	99.54	99.74	99.45

I. Magnesite from Chiles Valley, Napa County. P. H. Bates, analyst.

II. Magnesite from W. W. Burnett's ranch, Coyote, Santa Clara County. A. J. Peters, analyst.

III. Magnesite from near Morgan Hill, Santa Clara County. A. J. Peters, analyst.

[10] F. L. Hess, "The Magnesite Deposits of California," Bull. 355, U. S. G. S., Washington, 1908.

Tremolite was found at two places in connection with the serpentines in the neighborhood of the Culverbear group of quicksilver mines in Sonoma County and at the Redwood area of serpentine in San Mateo County. Small lenticular bodies are imbedded in the serpentine. More often they are found as float. They reach a diameter of four to five inches, are usually coated with iron stain, and are exceedingly tough. The mass has a somewhat schistose structure and when broken shows needle-like white crystals with a silky luster.

The microscope shows an interwoven mass of slender crystals. Some few are of stocky habit but with no definite shape. A cleavage parallel to the elongation and a cross fracture is present but not pronounced. The extinction is parallel in some sections, in others it varies. The maximum angle measures about 22 degrees. The slower ray is parallel to the elongation of the crystal and sections with parallel extinction show the emergence of an optical axis. The trace of the optical plane lies parallel to the cleavage. Sections cutting at right angles the plane of schistosity show a characteristic amphibole cross section with a pronounced prismatic cleavage of about 124 degrees.

Inclusions of a dark green mass of antigorite are frequent. The alteration of it into tremolite is plainly visible. It begins first on edges. Bunches of needle-like crystals are tangent to the more or less oval-shaped body. Their higher interference colors contrast sharply with the low birefringence of the antigorite.

The serpentine is dotted with specks of a brighter color. Under a high-power objective they resolve themselves into radiating bundls of fibers of tremolite. The process of alteration is therefore not confined to the boundaries of the mass but is also an internal one.

Tremolite was also observed in a section from a pseudomorph after a websterite from Mount Diablo.

Talc is very rarely found in connection with the serpentines. At the Redwood area it was found in place secondary after tremolite.

Hydromagnesite.—This mineral is a product of decomposition of the serpentine. Local conditions seem to influence its formation, as it is more abundant in some localities than in others. In the Sulphur Creek areas it is abundant.

It occurs in white chalk-like masses to which green inclusions of serpentine give a mottled appearance and which readily crumble away under slightest pressure. The ratio of serpentine to hydromagnesite is approximately as one is to two. An analysis of the purest sample gave results as follows:

ANALYSIS OF HYDROMAGNESITE.

H. E. Kramm, analyst.

SiO_2	9.37
Fe_2O_3 / Al_2O_3	trace
CaO	2.46
MgO	39.25
CO_2	29.45
H_2O	18.74
	99.27

Crystals of hydromagnesite are found near Cedar Mountain in Alameda County.

Calcite occurs as veins in the serpentine and is a prominent constituent of the silicious mass to which serpentine gives rise. It is also found closely associated with the serpentine in what is known as ophicalcite. Specimens of ophicalcite which are a mixture of about one half calcite and one half serpentine were found at the Mirabel Quicksilver Mine in Lake County and at New Almaden in Santa Clara County.

Dolomite has an occurrence similar to that of calcite.

Aragonite is found in the neighborhood of Pine Mountain. At the Helen quicksilver mine in Sonoma County it occurs as needle-like crystals and fibrous crusts.

Epsomite. This mineral is found lining the shaft and drifts in the Knoxville Mine. Hair like crystals, snow white in color, somewhat brittle, with a silky luster often reach a length of a foot or more.

Melanterite is usually found as greenish-white hair-like crystals reaching a length of several inches, lining shafts and drifts in quicksilver mines. In the Knoxville mine it also occurs in stalactitic masses of a pale green color, which seem to melt in their own water of crystallization. On exposure to light it becomes dry, assumes a yellowish-green color and changes into copiapite.

Copiapite is less abundant than melanterite, the oxidation of which gives rise to it.

Redingtonite was first found in the Redington Mine at Knoxville and described by Dr. Becker.

Knoxvillite, according to Dana, occurs with redingtonite at Knoxville.

Limonite and hematite are products of decomposition of the serpentines and impart the red color to the soil derived from it. Commercially they are not important on account of impurity.

Conclusions.

In the preceding pages the following facts are demonstrated:

(A) The serpentines are derived from basic eruptive rocks.

For this speaks the irregularity of the serpentine bodies, which is a typical character of eruptive rocks. A glance upon the map also shows that, with the exception of the Mount Diablo serpentine, the areas have an approximately northwest-southeast trend, which corresponds to lines of structural weakness in the Coast Ranges.

Furthermore, the serpentine contains olivine and chromite. The first, with the exception of altered magnesian limestones, is found only in eruptive rocks.

The second has, to the writer's knowledge, never been found in serpentine derived from sedimentaries.

The chemical composition of the serpentine shows it to be related to peridotites.

Pseudomorphs after pyroxenites are not very well possible in serpentine derived from sedimentaries.

(B) This eruptive rock was fairly uniform and its time of intrusion falls in a period which followed the deposition of the Knoxville beds.

The uniformity is demonstrated by the analyses of the rock which show it to be of a basic nature.

The mineralogical investigation shows it to be a lherzolite, and the serpentine derived from it a lherzolite serpentine.

However, variations in this rock occur which are represented by lenticular bodies of pyroxenites which are usually of small dimensions, but sometimes reach considerable size as in the case of the Mount Diablo pyroxenite.

The age of the serpentine is established by field evidence which agrees with that of Turner and Fairbanks and makes the serpentine post-Knoxville.

(C) Other facts which are of petrological interest are:

The lherzolite is in an advanced state of decomposition.

The freshest specimen found contained only about twenty per cent. of the original constituents of the rock.

Olivine readily undergoes decomposition. Enstatite and diallage are more resistant, and the latter seems to be more susceptible towards serpentinization than the former.

Picotite is quite abundant in fresh specimens of the northern areas and appears to give rise to chromite.

Secondary minerals besides the usual products of decomposition are spinel, tremolite and talc.

In closing the writer wishes to express his obligation to Professor A. F. Rogers, of Stanford University, under whose guidance and advice this paper was prepared.

TABLE OF ANALYSES.

Serpentines.

	I.	II.	III.	IV.
SiO_2	36.57	37.62	37.71	39.60
Al_2O_3	.95	1.20	1.81	1.94
Fe_2O_3	7.29	8.60	10.47 (with FeO)	——
FeO	.37	2.15		
MgO	40.27	37.59	35.60	36.90
CaO	.14	2.49	——	——
Na_2O	.31	.27	——	——
K_2O	trace	trace	——	——
H_2O	13.37	10.46	——	12.91
MnO	.10	——	——	——
Cr_2O_3	.33	.36	——	.20
TiO_2	——	trace	.09	——
NiO	.31	——	——	——
	100.01	100.74	85.68	100.00

I. Bastite with fine seams of chrysotile from Mount Diablo. W. H. Melville, analyst.

II. Serpentine from Sulphur Creek, Colusa County. H. E. Kramm, analyst.

III. Serpentine from Oak Hill. Partial analysis by U. S. G. S.
IV. Serpentine from Presidio, San Francisco. J. D. Easter, analyst.

	V.	VI.	VII.	VIII.
SiO_2	39.64	39.98	40.50	41.52
Al_2O_3	1.30	1.12	.78	1.57
F_2O_3	——	13.19	4.01	3.50
FeO	7.76	1.05	2.04	1.07
MgO	37.13	30.49	37.43	36.84
CaO	——	.46	.39	.44
Na_2O	——	.28	.28	——
K_2O	——	.25	.16	——
H_2O	13.81	13.26	13.75	15.83
MnO	.12	——	.13	.29
Cr_2O_3	.29	trace	.41	——
TiO_2	——	tarce	——	——
NiO	.33	——	.11	——
P_2O_5	——	——	trace	——
Total	100.38	100.08	99.99	101.06

V. Black impure serpentine from near Borax Lake, Lake Co. Monograph XIII., U. S. G. S., 1888, p. 111. Analyst not stated.

VI. Serpentine from Mayacmas Range. H. E. Kramm, analyst.

VII. Serpentine from Mount Diablo. W. H. Melville, analyst.

VIII. Serpentine weathered interwoven with quartz and calcite from Mount Diablo. W. H. Melville, analyst.

Table of Analyses.

Serpentines.

	IX	X.
SiO_2	41.86	42.06
Al_2O_3	.69	2.72 (with Fe_2O_3)
Fe_2O_3	——	
FeO	4.15	2.88
MgO	38.63	39.53
H_2O	14.16	12.04
MnO	.20	——
Cr_2O_3	.24	——
NiO	trace	——
	99.93	99.23

IX. Pure serpentine from near Borax Lake, Lake County. Monograph XIII., U. S. G. S., 1888. Analyst not stated.

X. Serpentine from Angel Island. F. L. Ransome, analyst.

TABLE OF ANALYSES.

Pyroxenites.

	XI.	XII.	XIII.
SiO_2	42.76	53.25	56.98
Al_2O_3	5.71	2.80	1.73
Fe_2O_3	3.16	.69	4.04
FeO	3.30	5.93	4.18
MgO	27.11	19.91	27.40
CaO	10.03	16.22	3.26
Na_2O	2.24	.19	.59
K_2O	.49	trace	.35
H_2O	4.85	.29	2.04
MnO	——	.09	——
Cr_2O_3	.22	.54	.09
TiO_2	.17	——	none
NiO	——	.07	——
Total	100.04	99.98	100.66

XI. Pyroxenite-peridotite from Oak Hill near San Jose. H. E. Kramm, analyst.

XII. Fresh pyroxenite with some olivine from Mount Diablo. W. H. Melville, analyst.

XIII. Enstatite pyroxenite from near Coyote, Santa Clara Co. H. E. Kramm, analyst.